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A RECONSTRUCTION OF WATER PLANES OF THE EXTINCT GLACIAL LAKES IN THE LAKE MICHIGAN BASIN[1]

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THE RAISED BEACHES

Around the borders of Lake Michigan are many fragments of abandoned shore lines, which stand at different heights above the present lake. They mark a series of stages of extinct lakes of late glacial times, known as Lake Chicago, Lake Algonquin, and the Nipissing Great Lakes. Near the south end of the lake, where erosion has been slight and the accumulation of shore drift has been going on since the earliest times, there is a record of nearly all the stages through which the lake has passed. On both the east and west sides of the lake, however, in Michigan and Wisconsin, where the cutting back of cliffs at the present level of Lake Michigan has been vigorous, the old shore lines have been partly or wholly destroyed for stretches of five to twenty-five miles. Even where the present lake has not cut away the record, it is usually incomplete, because the higher beaches have been destroyed by cliff recession during the lower of the extinct stages. It follows that the old shore lines preserved at one locality do not necessarily correspond with those at a neighboring locality, either in number or in order. The matter of correlation is not a very simple one; the highest beach at a given locality may not correspond with the highest at a neighboring locality, even though it may be less than a mile away. Moreover, while the beaches around the south end of Lake Michigan are still horizontal, having been undisturbed by earth movements since they were formed, those in the more northerly portions have been affected by repeated differential uplifts. Each beach rises northward at a rate different from those above and below it, and at a rate which increases repeatedly in a northward direction. At one or more points, the planes marked by the inclined beaches split, vertically, so that a single stage in the southern part of the lake represents fifteen or twenty stages in the northern part. This is the result of the repeated tiltings of the northern district. The problem of proper correlation of the fragments, then, and of the complete reconstruction of the old water planes is a very difficult one. Not only must as many of these fragments as possible be discovered, but at each locality every beach and terrace of the series must be noted, its strength and peculiar characters recorded, and its altitude measured with all possible precision.

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[1] With the permission of the Director of the U. S. Geological Survey.

The raised beaches about the south end of Lake Michigan have been described in detail by Leverett,[1] Alden,[2] and others. The beaches along the west side of the lake, in eastern Wisconsin, were first studied in detail by the present writer,[3] in 1905. The planes which were recognized there have since been traced farther north in the upper peninsula of Michigan, by Hobbs.[4] On the east side of the lake, Taylor and Leverett have for several years been accumulating detailed information concerning the beaches. It was with the purpose of supplementing this work by a series of more detailed and precise measurements, and thus establishing more definitely the identity of certain beaches, and their relations, that the writer, under Mr. Taylor's direction, undertook a six weeks' survey of the shore lines along the east side of Lake Michigan in July and August, 1907, for the U. S. Geological Survey. The method of measurement and of assembling the data secured in this study is the same which had been used in eastern Wisconsin in 1905. It was unnecessary in this case, however, to spend much time in exploration; for Mr. Taylor had selected a large number of localities where measurements could be made most advantageously. Considering the shortness of the season, therefore, the field covered was a large one, and the results obtained were unusually complete.

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[1] Frank Leverett, "The Illinois Glacial Lobe," *U. S. Geol. Surv.* (Monog. XXXVIII), 1899; also earlier papers (see *op. cit.*, p. 419).

[2] W. C. Alden, "Chicago Folio," Geologic Atlas of U. S., *U. S. Geol. Surv.*, Folio 81, 1902; "The Delavan Lobe of the Lake Michigan Glacier of the Wisconsin Stage of Glaciation, and Associated Phenomena," *U. S. Geol. Surv.* (Prof. Paper 34), 1904; "Milwaukee Special Folio," Geologic Atlas of U. S., *U. S. Geol. Surv.*, Folio 140. 1906.

[3] J. W. Goldthwait, "Correlation of the Raised Beaches on the West Side of Lake Michigan," *Jour. Geol.*, Vol. XIV, pp. 421–24, 1906. "Abandoned Shore-Lines of Eastern Wisconsin," *Wis. Geol. & Nat. Hist. Surv.* (Bull. xvii), 1907.

[4] For the Mich. Geol. Surv. Results not yet published.

The old water planes, or imaginary surfaces of the extinct lakes, are marked by a variety of shore features. One type which is common on both the past and present shores is the cut bluff and bench. As developed along the present shore of Lake Michigan, the steeply sloping bluff or cliff rises from the water's edge, while the bench or terrace at its base reaches out under water. The point at the base of the bluff or the top of the bench is approximately the highest point at which erosion by storm waves is effective. It is usually a little above the normal lake level. Where bedrock cliffs instead of clay bluffs form the coast, however, the bench is perhaps likely to be a little lower than lake level. There is a constructional variation here of a few feet, but of only a few feet, in the case of Lake Michigan. In making measurements on such a bench, to determine the altitude of the old water plane, the base of the bluff was always taken. It is the only determinable point that one can take as a standard. Care was taken, of course, in making these measurements, to avoid places where the bench had been built up by landslides, or by alluvial wash down the face of the bluff, or where it had been gullied by streams. A range of error of five feet would probably be quite enough in this region to allow for discordances of benches due to original constructional variation in height.

Quite a different feature of topography is the beach or beach ridge —a line of shore drift banked up by the waves at or close to the water's edge, and rising only as high as storm waves can fling material. In exposed places on the shore of Lake Michigan, beaches have been observed whose crests stand fully six feet above calm water level. As a rule, however, they stand only three or four feet above it. In rare cases, where local conditions favor a heavy surf, the beaches probably attain a height of eight or even ten feet. The crest of a beach, however, is the only point which one can take as a criterion for measuring a water plane; so in the study of these raised beaches it is the crest that has been measured each time. Care was taken to make sure of the presence of gravel on the surface of these beaches, in order to eliminate the effects of wind-blown sand, which often raises a beach, locally. If we allow a range of five feet for original variation in height of beach crests, we have probably satisfied all discordances except those which can be recognized as due to peculiar local conditions.

Other varieties of the beach need scarcely be mentioned, such as the bar or barrier, built between headlands, in comparatively deep water. Its height is liable to be more extreme on that account. The object in the foregoing remarks is to show that the points selected for measurement (the base of a bluff, or the crest of a beach or barrier) were chosen for convenience, not to say from necessity, and that an original constructional variation in height of about five feet is fully recognized.

METHOD OF INVESTIGATION

In the measurements the spirit- or Y-level was used almost exclusively, and to decided advantage. While much has been accomplished with the hand level and aneroid, in skilful hands, neither of these instruments has the accuracy or reliability of the Y-level. The influence of weather conditions, especially lake breezes, on the aneroid, and the personal equation in the hand level are liable to cause mistakes in such work as this. Where there is a whole series of shore lines to be measured in one locality and these beaches and benches follow one another in short vertical intervals, all possible accuracy in measurement is needed to correlate them, individually with members of a similar series at a neighboring locality. The Y-level, then, is almost indispensable for work in the central and southern portions of the Great Lake region, and desirable in all parts of it. Upham and Tyrrell used the Y-level[1] in measurements of altitude of the raised beaches of Lake Agassiz before 1890, Spencer[2] used it in

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[1] Warren Upham, "The Glacial Lake Agassiz," *U. S. Geol. Surv.* (Monog., XXV), p. 9, 1896.

[2] J. W. Spencer, "Deformation of the Algonquin Beach and Birth of Lake Huron," *Am. Journ. Sci.* Vol. cxli, pp. 12–21, 1891, and other papers.

Ontario at about the same time. Lawson[1] used it along the north coast of Lake Superior in 1891; but between that time and 1905, the hand level and aneroid were very generally used, instead; and accordingly the correlation and identity of the beaches of the Lake Michigan basin were imperfectly known.

Absolute accuracy is of course impossible even with the Y-level. On the one hand are original variations in height of the beaches and benches, due to local conditions under which they were constructed or cut; for which five feet has been allowed. On the other hand a certain amount of error is involved in the process of leveling; first, through the slight inaccuracy in the use of the instruments, and second, through the use of Lake Michigan as the datum or starting-point. It frequently happened, on days when levels had to be run, that a strong on-shore wind was blowing and the waves were running high, so that one could not tell within half a foot what the normal level of the lake would be at that place. To be quite fair, then, we must expect in these measurements occasional discordances due to a combination of these errors of six feet or so.

THE SHORE LINES OF LAKE CHICAGO

The old shore lines fall into two distinct groups. There is an earlier group, well registered around the south part of Lake Michigan, but unknown in the northern part. These belong to the so-called Lake Chicago, a lake which was confined to the Michigan basin, with its outlet at the extreme southwest corner, into the Desplaines valley at Chicago. A later group, represented by but a single shore line in the southern part of the basin, below the beaches of Lake Chicago, but rising to a considerable height northward, and splitting into a large vertical series, records the complex history of Lake Algonquin and the Nipissing Great Lakes.

The shore lines of Lake Chicago, as distinguished at the south end of the basin, and described by Leverett and Alden, mark three distinct stages, to which the names Glenwood (or 60-foot), Calumet (or 40-foot) and Toleston (or 20-foot) stages have been given. To be more exact, the average altitudes of these three shore lines are 55,

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[1] A. C. Lawson, "Sketch of the Coastal Topography of the North Shore of Lake Superior, with Special Reference to the Abandoned Strands of Lake Warren," *Minn. Geol. Surv.*, 20th Ann. Rept. p. 231.

38, and 23 feet above Lake Michigan, or approximately 636, 619, and 604 feet above sea level. In the following table, the altitudes of these beaches is given for six selected localities, where spirit-level measurements have been made by the writer.

Locality	Miles North of Chicago	Glenwood	Calumet	Toleston
Evanston and Niles Center, Ill.	15	636′	619′	605′
Zion City, Ill.	43	634′	621′	x
State Line, Ill., and Wis.	46	634′	616′	x
Line between Racine and Kenosha counties, Wis.	57	637′	621′	. . .
Holland, Mich.	65	638′	621′	605′
Spring Lake and Eastmanville, Mich.	87	633′	(613′)	602′

It will be noticed that the first four localities are on the west side of Lake Michigan. The last two are on the east side. Spring Lake and Eastmanville are near Grand Haven. The symbol "x" in the table indicates that the shore line is missing because of destructive cliff cutting at a lower stage. Other measurements might be given, less accurate than these, but confirming them, almost without exception. They indicate that as far north as a line through Grand Haven, Mich., and Milwaukee, Wis., the three beaches of Lake Chicago are horizontal. The terrace at Eastmanville, given at 613′ in the table above, is so obscure a feature that its exact altitude cannot be estimated within several feet. Disregarding this one measurement, then, the data show a remarkable accordance in the altitude of beaches, the variation being not more than five feet for each stage. That much variation, as has already been remarked, must be expected in the original construction of the beaches. There is no indication of system in the slight departures from uniformity of height from north to south, hence no reason to suppose that any of these water planes are inclined at all south of Grand Haven and Milwaukee. Apparently, then, these beaches, representing the earliest stages of the lakes of late glacial times have been unaffected by any of the earth movements which are known to have deformed the central and northern portions of the Great Lake region since the ice withdrew.

On the accompanying map (Fig. 1) the northern limit of horizontality for these beaches of Lake Chicago is indicated by a line;

and this line is extended east and southeast through Lake St. Clair and Ashtabula, Ohio, so as to mark the corresponding limit for the beaches of Lakes Maumee and Whittlesey in the Erie basin, as determined by Leverett and Taylor. South of this line, then, there seems to have been no subsequent deformation in either the Michigan or the Erie basins.

Beyond Grand Haven, on the east side of the lake, the data recently collected at several localities, as far north as Ludington, indicates that the beaches rise northward and increase in number; but the precise correlation has not been possible for several reasons. The measurements are as follows:

Locality	Distinct Beaches at
Muskegon	604′, 609′, 613′–616′, 628′
Montague	632′, 634′, 656′, 658.
Bass Lake	628′–630′, 639′, 642′, 649′–650′.
Ludington and Amber	636′–640′, 673′–675′.

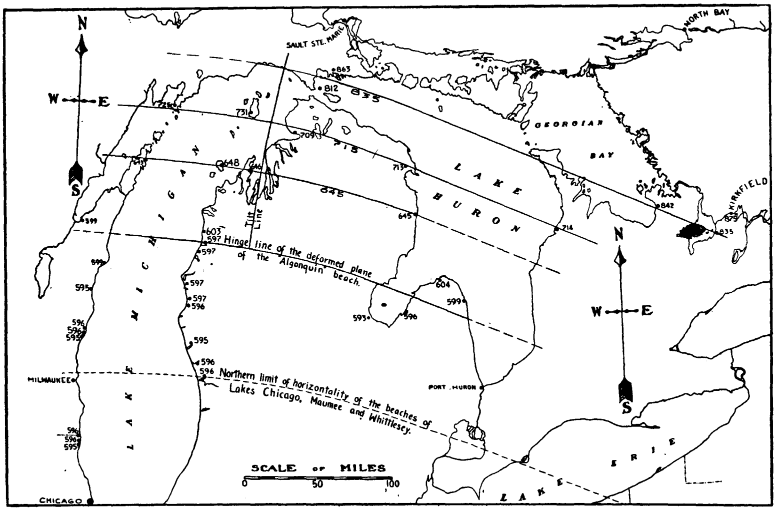

FIG. 1.—Map of Lakes Michigan and Huron, showing northern limit of horizontality of the beaches of Lakes Chicago, Maumee and Whittlesey, altitudes of the Algonquin beach at selected localities, and isobases of deformation and line of maximum inclination of the warped Algonquin water plane.

The fragments north of Grand Haven are scarce and generally obscure, becoming sandy and irregular as they go north. It appears as if they were approaching the ice border for those stages, and fading away among the moraines. Those beaches which locally show strong development cannot be grouped into a single system of diverging planes like the Algonquin beaches presently to be described. The rate of inclination from south to north is hardly one foot per mile. It is possible, then, that the southward slant of these beaches is due wholly to ice attraction, according to the calculations of R. S. Woodward.[1] Assuming an ice sheet of reasonable extent and thickness, Woodward found that its attraction might be sufficient to raise the surface of the lake nearby into a curve, concave upward, with an apparent inclination of several inches to the mile for the first fifty miles or so from the ice border. If this be the right explanation for the Lake Chicago beaches north of Grand Haven, it accounts for the apparent lack of harmony between the measurements; for the relation of successive water planes to each other would be similar to the branchings of a feather (see Fig. 2) and the few points where measurements have been made might happen to lie on several different divergent surfaces. If, on the other hand, the northward ascent of the beaches is due to a series of differential uplifts of the region, these uplifts must have occurred before the formation of the next lower beach, the "Algonquin" beach, for that beach is horizontal over the whole southern half of the Michigan basin.

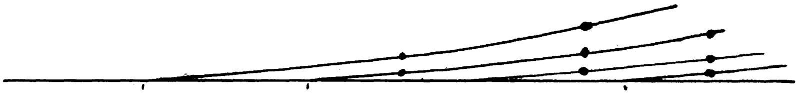

FIG. 2.—Diagram showing how a series of ice-attracted water planes might look, in profile.

North of Ludington little is known of these beaches, and no measurements have been made. While the Glenwood and Calumet shore lines might expectedly terminate at any place, against a moraine, the Toleston or lowest shore line of Lake Chicago ought to extend northward to the place where the ice border first uncovered a low pass leading across Michigan into the adjoining Huron basin, probably east of Little Traverse Bay. No traces of such a beach are known. It is probable that the record is too weak and obscure to be recognized.

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[1] R. S. Woodward, "On the Form and Position of the Sea Level," *U. S. Geol. Surv.* (Bull. 48. p. 88), 1888.

THE ALGONQUIN BEACH

Below the beaches of Lake Chicago, encircling the south end of Lake Michigan, is the Algonquin beach. It rises northward, in the central and northern part of the basin, as shown by the map, Fig. 1. The identity of this beach, the highest shore line on Mackinac Island, as the "Algonquin" beach[1] of Spencer was long ago recognized by Taylor. On the map, Fig. 1, can be seen the altitude of this Algonquin beach at about thirty-five selected localities in the Huron and Michigan basins. The warped attitude of the water plane which passes through these points is indicated by the system of isobases and the line of maximum inclination which runs perpendicular to them. The data have been taken from several sources. The measurement on the Garden peninsula (725′) is one of many made by Hobbs in 1907. The twenty or more remaining measurements around Lake Michigan and the Straits of Mackinac were made by the present writer, in company with F. B. Taylor, in 1907. On the west side of Lake Huron the measurements were made by Frank Leverett, A. C. Lane, W. M. Gregory, W. F. Cooper, and C. A. Davis. East of Lake Huron the measurements are all Spencer's except the one at Beaverton, which was recently made by Taylor.

Recent investigations by Taylor in Ontario, supplementing earlier studies, indicate that this beach marks a period of activity of *two* outlets, one at Port Huron and one east of Kirkfield, Ontario, where there was an overflow into the valley of the Trent River. This Algonquin beach, of the "two-outlet" stage, seems to be the highest beach common to the Huron and Michigan basins. This gives reason to conclude that when the ice border south of the Straits of Mackinac withdrew so as to let the waters of the Michigan basin merge with those of the Huron basin, the "Trent outlet" was already running. Had the lakes merged before the Trent pass was uncovered and while the Port Huron outlet alone was active, then the plane of that beach, adjusted to the Port Huron outlet, would have been temporarily abandoned when the Trent pass was uncovered, and the waters fell to a low level; and the subsequent uplifts which raised the

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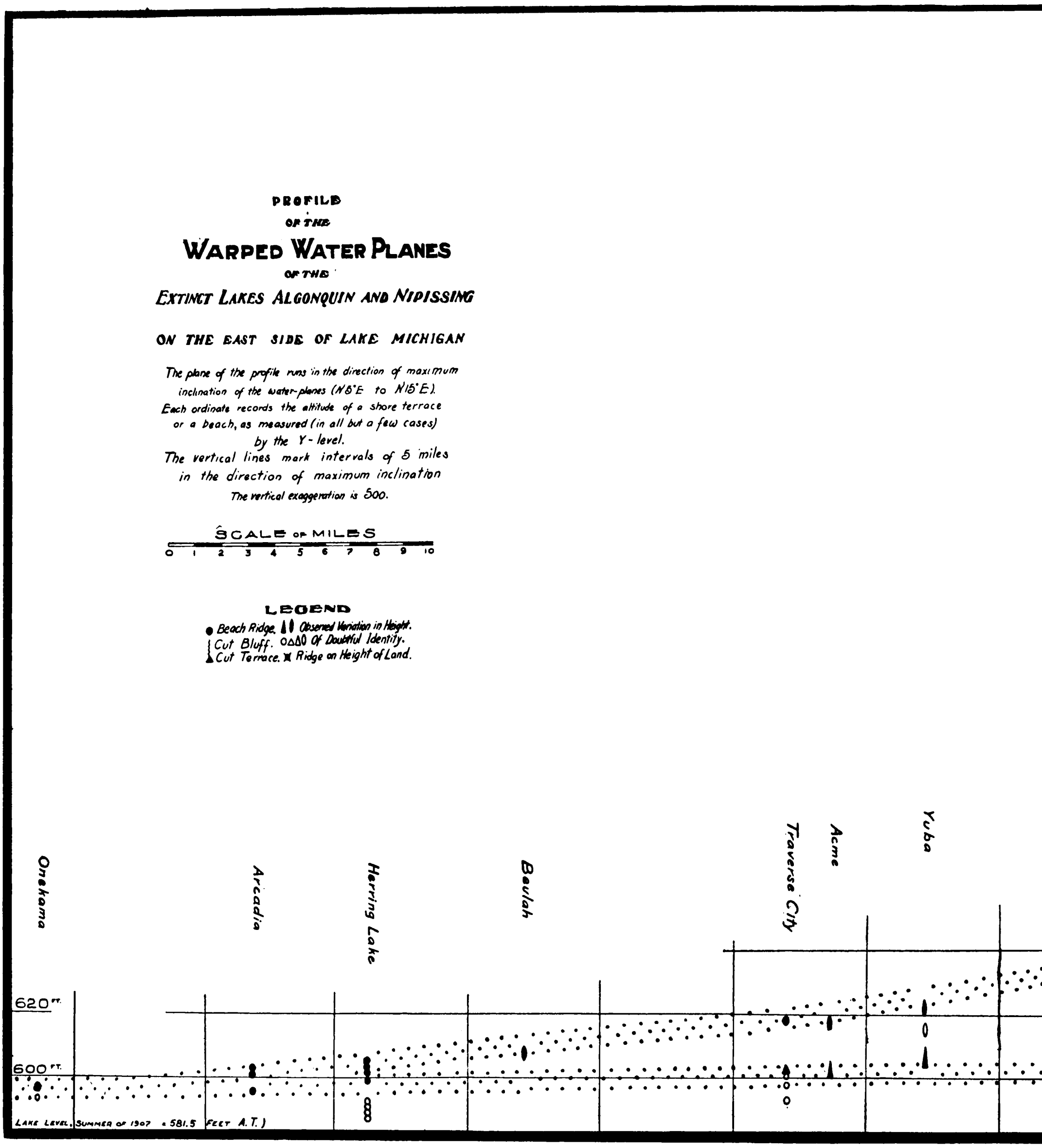
[1] J. W. Spencer, "Notes on the Origin and History of the Great Lakes of North America" (abstract), *Am. Assoc. Adv. Sci., Proc.*, Vol. XXXVII, pp. 197–99, 1889, and later papers.

Trent pass up to the level of the one at Port Huron would have raised this old plane (within this region of deformation) well above any subsequent level of the waters. No such plane above the Algonquin beach of the "two-outlet stage" is known, unless it be the Toleston beach. As already noted, this beach is lost, north of Ludington, and no beach is known in the Huron basin which connects with this in the northern part of the lower peninsula of Michigan.

CONSTRUCTION OF A PROFILE OF WATER PLANES

The altitudes of the Algonquin beach at about fifty localities in the northern part of the Michigan basin is shown in Fig. 3. This is a miniature copy of a large scale chart (composed of sheets of the U. S. Lake Survey) on which the data collected in 1905 and 1907 were plotted for final inspection. Through and among these points, a series of isobases was drawn with a vertical interval of ten feet. These were found to be parallel to each other, and to be in harmony with the similar lines across the Huron basin, as shown in Fig. 1. Across the isobases was then drawn a line in the direction of maximum inclination—a gentle curve that changes gradually from N. 15° E. near the Straits of Mackinac to N. 5° E. south of Grand Traverse Bay. With this map as a basis for locating points, a profile of the Algonquin beach and the complex series of shore lines below it was then drawn, as follows: Upon the line of maximum inclination was plotted the position of each station on the east side of the lake where measurements had been made. Each one was then transferred directly to a sheet of co-ordinate paper, on which distances from left to right represented distances from south to north. A horizontal line at the base was taken to represent the present level of Lake Michigan (581.5 feet A. T. in July and August, 1907). With a vertical scale of 20 feet to the inch (500 times as large as the horizontal) the altitude of every beach and bench was recorded by an ordinate. These ordinates served to reconstruct the water plane in profile. A reduced copy of this profile constitutes Plate I. In it, between Hessel and Onekama, a distance of 125 miles, over 25 different lines of levels at as many localities along the east side of Lake Michigan are represented. In other words, the stations are on the average 5 miles apart. About 190 measurements are on well-formed beaches or benches, and


PROFILE OF THE WARPED WATER PLANES OF THE EXTINCT LAKES ALGONQUIN AND NIPISSING ON THE EAST SIDE OF LAKE MICHIGAN

The plane of the profile runs in the direction of maximum inclination of the water-planes (N 8° E to N 15° E). Each ordinate records the altitude of a shore terrace or a beach, as measured (in all but a few cases) by the Y-level. The vertical lines mark intervals of 5 miles in the direction of maximum inclination. The vertical exaggeration is 500.

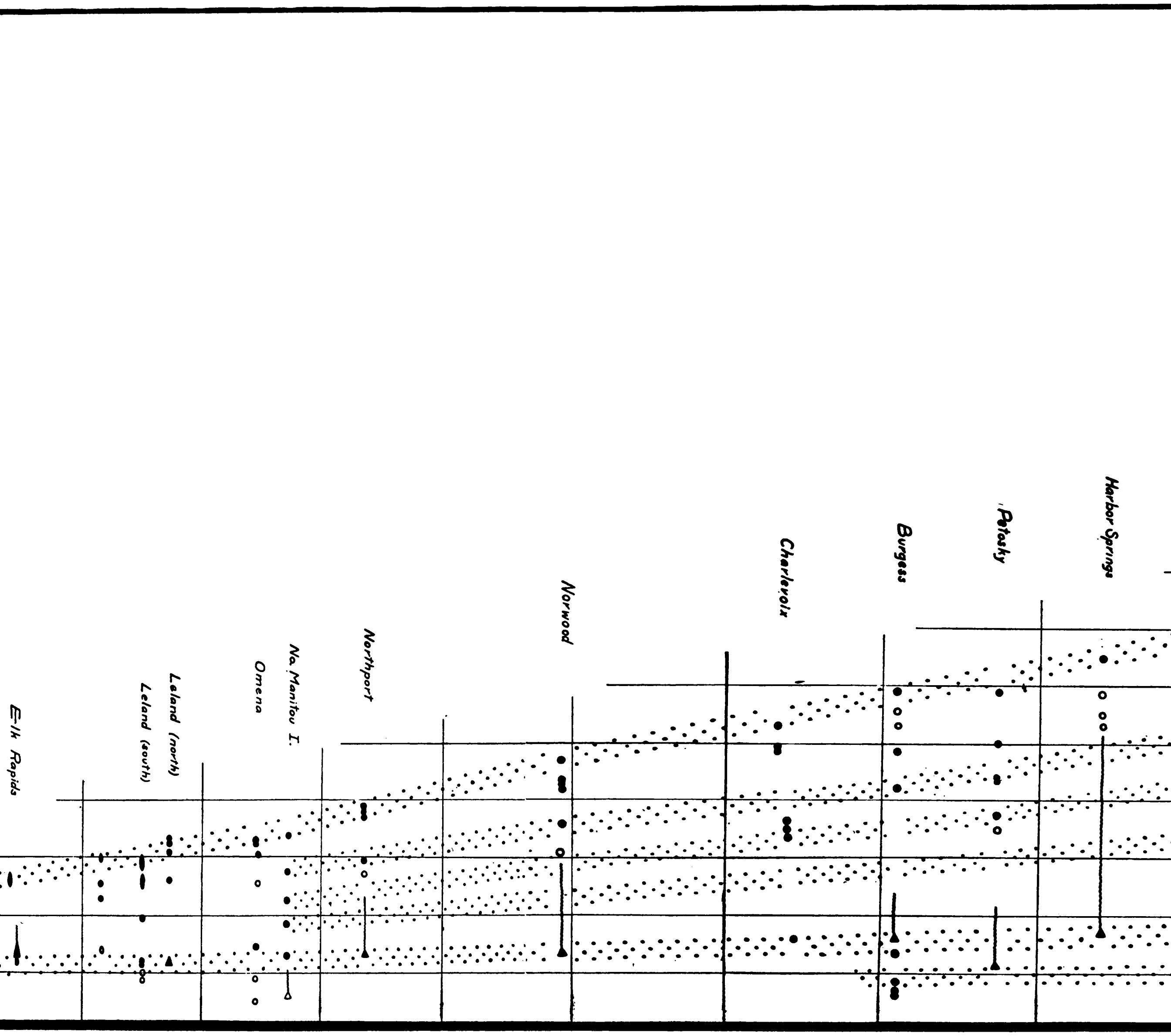
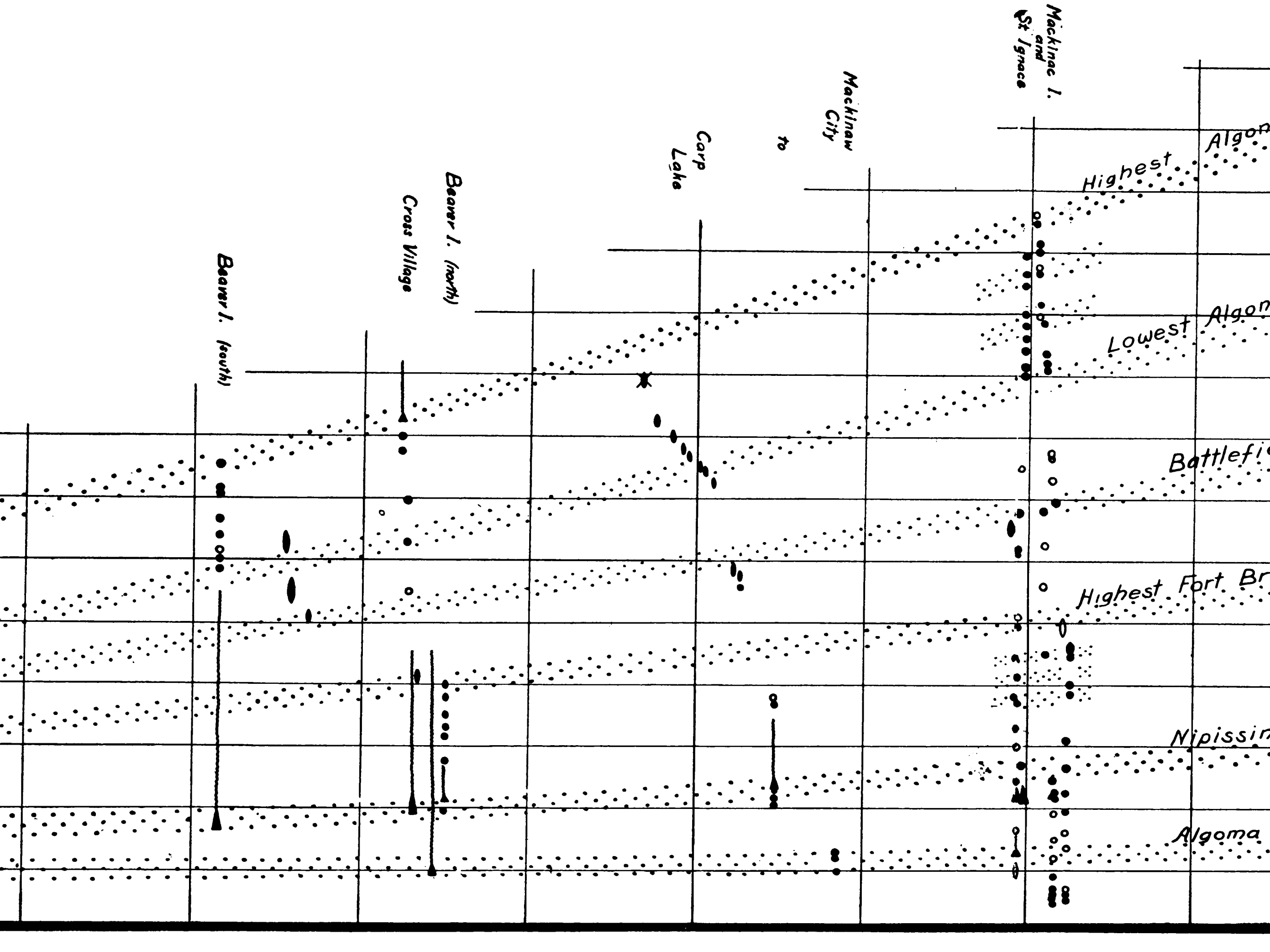


PLATE I.—Profile of the warped water planes on the east side of Lake Michigan, north of Onekama.


Beaver I. (south)
Cross Village
Beaver I. (north)
Carp Lake
to
Mackinaw City
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Highest Algon
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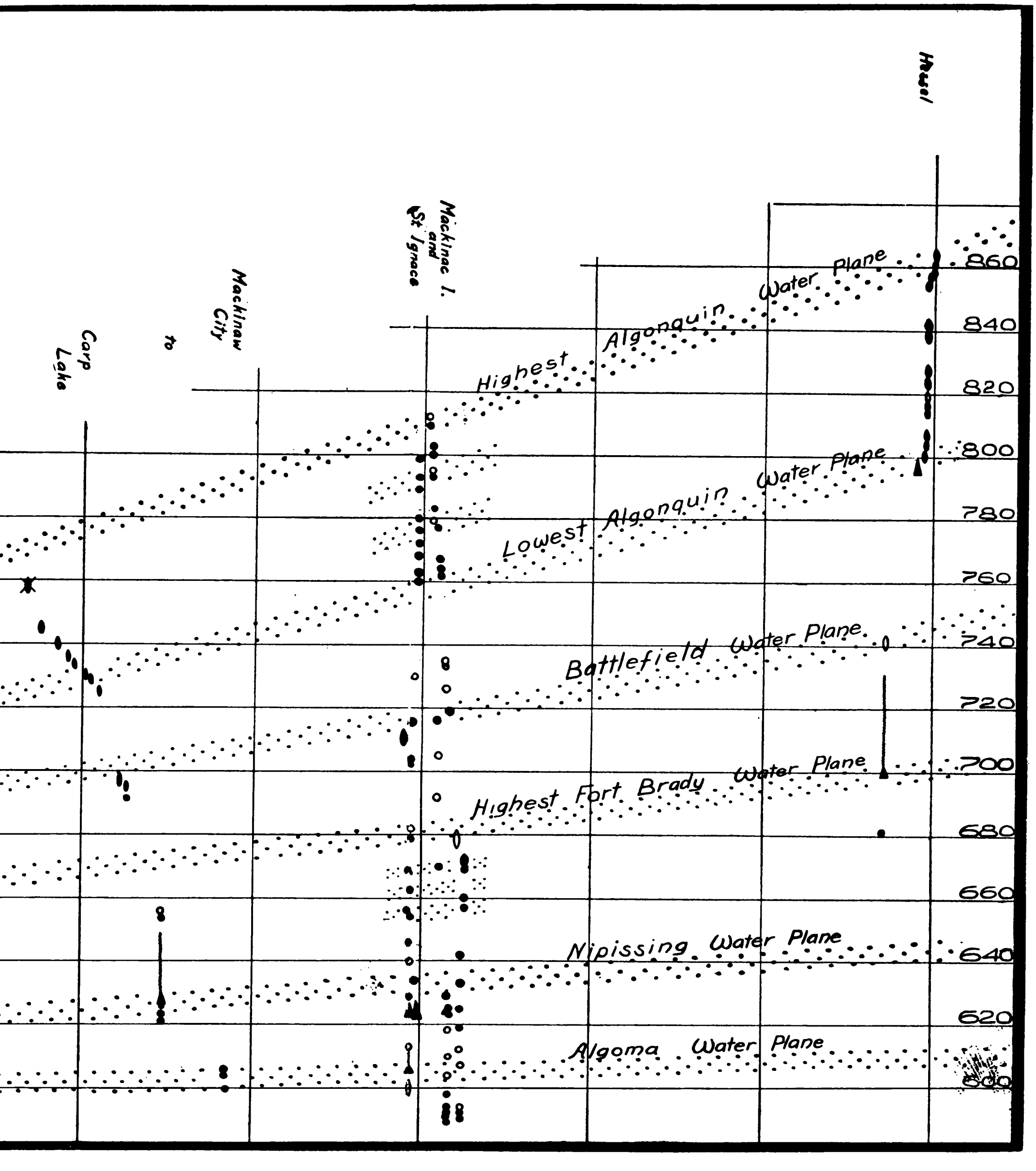
Battlefi
Highest Fort Br
Nipissin
Algoma


Hessel
Mackinac I. and St Ignace
Mackinaw City
to
Carp Lake
Highest Algonquin Water Plane
Lowest Algonquin Water Plane
Battlefield Water Plane
Highest Fort Brady Water Plane
Nipissing Water Plane
Algoma Water Plane
860
840
820
800
780
760
740
720
700
680
660
640
620
600

about 50 on beaches or benches that are less distinct, though not to be neglected in a fair consideration of evidence. A distinctive symbol is used for the two contrasted types of topography, benches and beaches; and the symbol for a well-formed beach or bench is different from the one for a beach or bench that is faint. The size of the spot is intended to cover the probable range of error in measurement. The height of a cut bluff is shown by a wriggling vertical line.

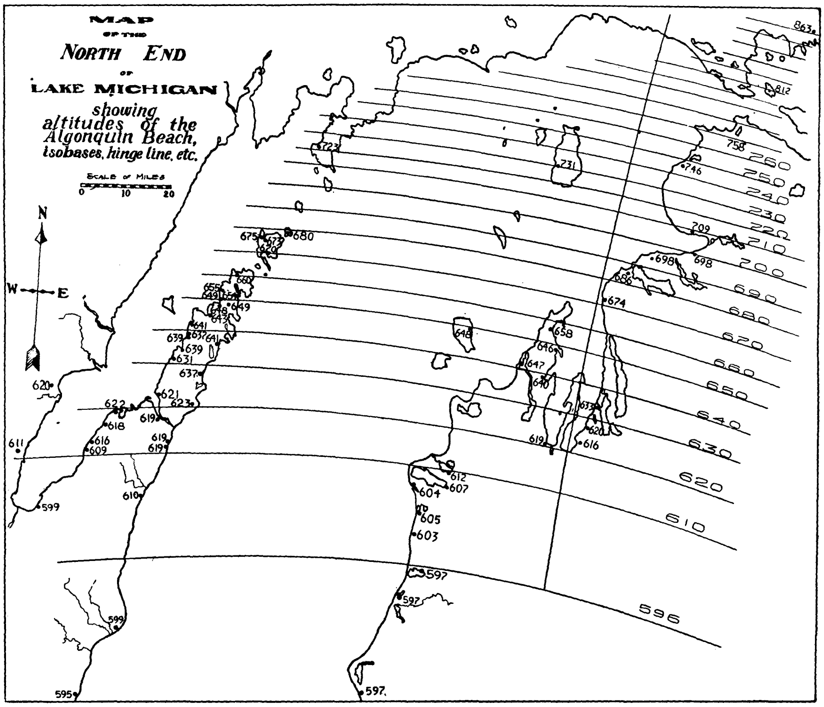


FIG. 3.—Map of the north end of Lake Michigan, showing the warped attitude of the Algonquin water plane.

Through the highest beach thus recorded a line or band was drawn with a thickness (according to the scale) of 6 feet, to represent the range of variation in height to be expected in the original construction of the beach or bench. The line or band, when drawn as a gentle curve, so as to pass most directly through the highest ordinates, includes 21 out of 24 of them. Of the 3 which are either too high or too low, to fall within it, one at Carp Lake, fully 8 feet too low, is easily accounted for. It is a beach ridge on a height of land, where no opportunity exists for the record of a higher stage. The other two discordant points, one at Petoskey and one at Leland, are five feet below and 4 feet above the center of the band, respectively, instead of being within 3 feet of it. This discordance of one or two feet is not a serious one; for it might be due to an error in leveling which augments an original variation in height, instead of being included in that variation.

The rate of inclination of this Algonquin plane measured from Hessel (at the ancient "Munuscong Islands") southward to Mackinac Island (15 miles) is 3.73 feet per mile. From Mackinac Island to Beaver Island (24 miles) it is 3.30 feet per mile. A rather rapid change of inclination near the isobase of Beaver Island introduces a tilt rate of about 2.00 feet per mile. Over the southern part of Grand Traverse Bay the rate again decreases, perhaps more gradually than in the former case, so that near Traverse City it is about 1.00 foot per mile. The further change from an incline to a horizontal position, which is accomplished near Onekama, seems to be a rather rapid one; for Onekama is only 25 miles south of Traverse City, where, as we have just remarked, the tilt rate is one foot per mile. The abruptness of the changes near Beaver Island and Onekam could be emphasized by representing the plane on the profile by a bent line rather than a curved one. The curve has been used here merely for simplicity, without meaning to imply that the deformation is necessarily a warping rather than an uplift by the tipping or jostling of large fault blocks. Either sort of uplift seems admissable, when due weight is given to the opportunity for variation in the height of the beaches or benches.

Below the highest shore line are a number of others. Some of them are equal to the Algonquin in strength; others are comparatively faint. They can best be recognized in the northern part of the region, where the vertical space between them is greater. On Mackinac Island, for instance, strong benches and beaches record ten lower stages of considerable importance. The Algonquin beach is the highest of a closely spaced group of ridges which are well displayed on the short target range back of Fort Mackinac. This "Algonquin group" of beaches occupies an interval at that place of about 50 feet.

The lowest of them and two intermediate ones are especially prominent. Forty feet below the Algonquins, and separated from them by an interval in which there are no plainly developed beaches or benches, is a beach of remarkable strength, called by Taylor the "Battlefield beach." It was so named because of its conspicuous development as a great ridge of cobblestones and gravel on the old battlefield, on the north slope of the island. Below the Battlefield beach another interval of 40 feet, unoccupied by any very persistent beaches, leads down to the group known as the "Fort Brady beaches." There are several of these ridges. Four of them fill a vertical interval of 25 feet; below them are at least two others of which we have a distinct record. A little below the Fort Brady beaches is the "Nipissing shore line," one of very remarkable strength. It is probably the most conspicuous of all the shore lines, and it is peculiar in consisting usually of a bench and bluff rather than a beach ridge. On Mackinac Island it stands 53 feet above Lake Huron, being represented there, however, by a great deep-water barrier which runs southwest from the Episcopal church. Below the Nipissing is one stage of importance, marked by the "Algoma shore line." At the Straits of Mackinac this stands about 25 feet above the lake.

All these shore lines and groups of shore lines—the Algonquin group, Battlefield beach, Fort Brady beaches, Nipissing shore line, and Algoma shore line—can be traced southward from the Straits of Mackinac, on this profile (Pl. I), with certainty for at least twenty miles, to Beaver Island, where they are all represented. But as they are followed further southward the record of them is found to become more and more imperfect and incomplete. The planes gradually converge until the discrimination between them becomes difficult; and what is more troublesome, in the development of cliffs at the lower stages (especially the Nipissing and the present stage) many of the higher beaches have been cut away and no record of them is left. The exact position of the planes between the Algonquin and the Nipissing, therefore, cannot be absolutely demonstrated, though a reasonable amount of confidence is placed in the reconstruction here given. In the case of the Nipissing shore line, however, there is no uncertainty. Its exceptional strength and peculiar character make it possible to follow this plane southward, down its gentle inclination of 0.75 feet per mile, diminishing to less than 0.50 feet per mile near Beaver Island, to Onekama, where it becomes horizontal and seems to unite with the Algonquin plane to form the single 596-foot plane already mentioned. While the data for the intermediate planes do not permit an unqualified statement, they seem to indicate that the lowest of the Algonquins, the Battlefield, and the Fort Brady beaches all converge to the same point, Onekama, instead of being overlapped, one after another, by the Nipissing. The Algoma plane seems to constitute another member of this split series; but its exact position south of Petoskey is somewhat in doubt.

It is perhaps possible that the highest Algonquin beach becomes horizontal at about 24 feet above Lake Michigan, near Herring Lake. This is suggested by the work of the present writer in eastern Wisconsin, and by the data thus far collected by those who have worked in the Huron basin. If so, the 14-foot "Nipissing shore line" seems to have very generally destroyed the 24-foot "Algonquin shore line" along the east side of Lake Michigan, south of Herring Lake. The evidence here seems rather to indicate that the Algonquin and Nipissing shore lines coincide to form the single 14-foot shore line. Figures 1, 3, and 5, and Plate I, embody this idea.

SIGNIFICANCE OF THE FAN-LIKE PROFILE

The steepness of inclination of these water planes, and their convergence to a single point, affords a basis for choosing between differential uplifts and ice attraction, to explain their present condition. At the Straits of Mackinac the calculated rate of inclination for the highest Algonquin is 3.73 feet per mile; for the lowest of the Algonquin group, 3.00 feet; for the Battlefield, 2.10 feet; for the highest Fort Brady, 1.29 feet; for the Nipissing, 0.75 feet; and for the Algoma, 0.33 feet. All those above the Nipissing slant too steeply to be accounted for by ice attraction. They must be explained by a series of earth movements which repeatedly raised the shore line of this region out of water. The Nipissing and the Algoma shore lines are inclined no more steeply than the surface of the lake close to the ice border might be inclined by ice attraction; but they are probably inclined more steeply than they could be so far from the ice border for the stages they represent. The ice front must have been at least

200 miles to the northeast of this region; for it had withdrawn from the Mattawa valley, east of North Bay (see Fig. 1), and at this distance its attraction on the waters would hardly have raised the lake surface more than an inch or two to the mile, according to Woodward's computations. Furthermore, the water planes come together at a single point. They should converge in turn to a series of points, feather fashion, if they marked the attraction of the lake to successive positions of the retreating ice front (see Fig. 2). Evidently, then, the inclined position of the planes, and their fan-like relation, must be attributed to earth movements.

The line from which the planes diverge (the "hinge line" on the map, Fig. 1), or as seen on the profile (Plate I) the point at which they split, might be determined, it seems, in either of two ways. It might mark the southern limit of a series of deformations, acting thus as a hinge on which the tiltings took place. If so, it is evident that here were no less than ten or fifteen distinct tilting or warping movements, all of which hinged on the same line. On the other hand, the point of splitting might be located at an outlet (or along the line of equal deformation through an outlet), which together with the region north of it had been raised by tiltings; for as the outlet rose, the horizontal surface of the lake would rise, south of it, drowning the old shore lines there, while to the north the former shore lines would be raised out of water each time and would come to form a fan-like series. This process is illustrated diagrammatically by Fig. 4.

The choice between these two explanations for the case at hand may be quickly made, if one considers the information shown on the map (Fig. 1). There are two outlets, only, which could possibly be associated with the splitting, viz., the Kirkfield and the Port Huron outlets. The isobase through the former (if it were drawn an 875-foot line, parallel to the 835-foot isobase on the map) would pass nowhere near Onekama, but rather through the upper peninsula of Michigan. That is a district as yet not critically examined. The Port Huron pass lies south of the "no tilt" line (or "hinge line" as it is called in Fig. 1); that is, it lies within the district which has been unaffected by uplifts; consequently no fan-like splitting can occur at it or in line with it. It seems necessary to conclude that Onekama lies on the hinge line of the tiltings which raised all the planes into their inclined positions. That so many tiltings, separated no doubt by considerable intervals of time, should have had the same hinge suggests that this line, for reasons unknown, is one of structural weakness.

In order to show the significance of the fan-like profile of water planes, in Plate I the following series of diagrams (Fig. 5) is introduced. These present in a very conventional and much simplified way the relation which the successive planes of Lake Algonquin and the Nipissing Great Lakes should bear to each other according to the present generally accepted interpretation of the history of the great Lakes, worked out by Mr. Taylor. Since that history is recognized as subject to revision, through further study, the diagrams should be taken to represent simply the conditions which seem most probable, in the light of the evidence already at hand. Although in the actual case the planes have been warped to curved profiles, as shown in Plate I, they are represented in the diagrams as simply tilted. This is wholly for the sake of simplicity, and must not be thought to imply that the crustal movements were actually tiltings instead of warpings.

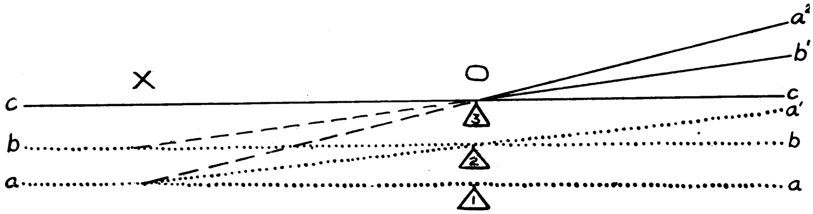


FIG. 4.—Diagram showing in profile how a fan-like group of water planes might be produced by a number of differential uplifts which tilted a lake basin and its outlet. Outlet at *O*. Uplifts affect region to the right of *X*. Three stages are shown. First stage, outlet at *1;* horizontal water plane of the lake at *aa*. Second stage, tilting on right side of *X* has raised outlet to *2;* water plane *aa* has been inclined to aa^1; the lake has risen to plane *bb*, drowning that part of it which lies on left side of outlet. Third stage, another uplift has raised outlet to *3;* has tilted *bb* to bb^1, and increased tilt of aa^1 to aa^2; lake has risen to *cc;* on left side of outlet planes *a* and *b* have been drowned; on right side, they rise, splitting at outlet, fan-fashion.

The final diagram (6, in Fig. 5) shows the present position of these planes. That portion which lies south of the Trent outlet is based on recent detailed work in the Michigan and Huron basins, including that described in this paper. The large profile, Plate I, corresponds with that part of Diagram 6. The remaining part, north of the Trent outlet, covers a large field in which studies have been less detailed and the reconstruction on that account cannot be regarded

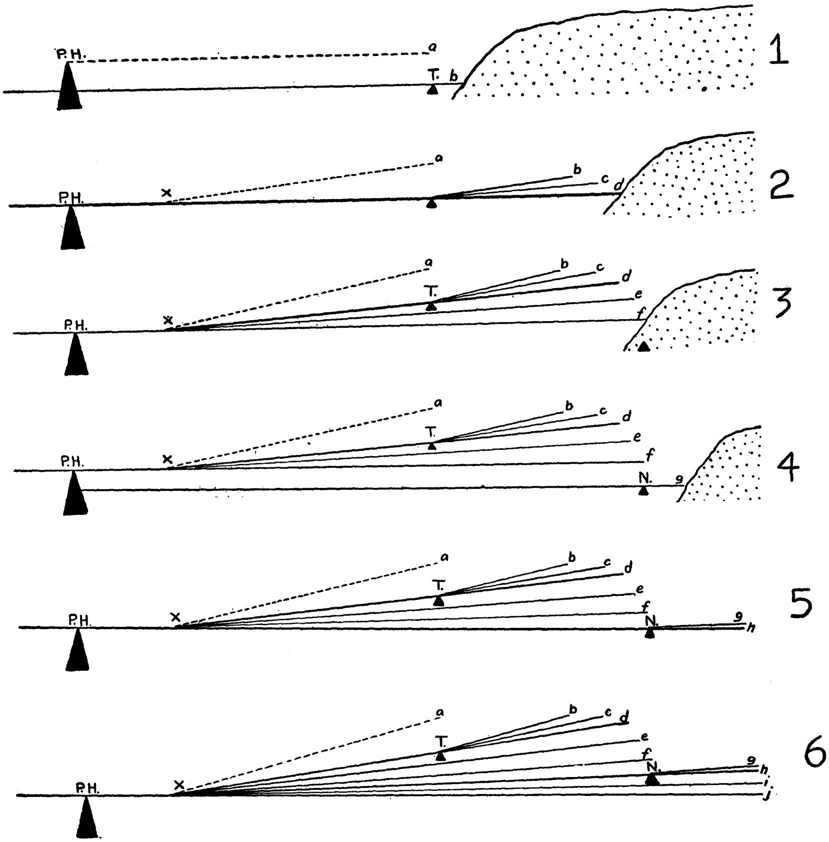


FIG. 5.—Diagrams showing how the water planes of Lake Algonquin and the Nipissing Great Lakes should be related, as seen in profile, if the generally accepted history of the lakes is correct. 1, 2, 3, 4, 5, 6, six selected stages in the lake history during the retreat of the ice border and the differential uplifts. X, the point on which the differential uplifts hinged, Onekama. The triangles represent outlets, the controlling point being the apex. *P. H.*, Port Huron outlet. *T*, Trent outlet. *N*, Nipissing outlet. *a*, *b*, *c*, *d*, *e*, etc., successive water planes of the lakes, in the order of their age. *a*, early Algonquin beach, unknown in the Michigan basin, but theoretically necessary in the Huron basin, *b*, *c*, planes of temporary low water stages through the Trent outlet; *d*, plane of the "Algonquin beach;" *e*, plane of the Battlefield beach *f*, plane of a Fort Brady beach; *g*, plane of a temporary low-water stage through the Nipissing pass, possibly marine submergence; *h*, plane of the Nipissing shore line; *i*, plane of the Algoma shore line; *j*, present plane of the Lake Michigan.

as actually established. From this series of diagrams it may be seen that (1) the "Algonquin" beach of the Michigan basin marks the "two outlet" stage when the discharge was shared between the pass at Port Huron and that at Kirkfield. Before it there had been a "low-water" stage, adjusted to the Trent (i. e., Kirkfield) outlet in its original low position; but earth movements had lifted the outlet, and consequently the lake level south of it to the level of the Port Huron pass. The records of this low water stage (southern continuations of planes *b* and *c*) have been drowned in the Michigan and Huron basins. The lower members of the group of Lake Algonquin beaches, the Battlefield and Fort Brady beaches, represent successive stages after the restoration of the Port Huron outlet (planes *e* and *f*). Each seems to record a differential uplift in which the northern part of the region was raised out of water, from a hinge near Onekama. The Nipissing plane (*h*) represents, like the Algonquin, a "two-outlet" stage, with the discharge divided between Port Huron and North Bay. Previous to it the low Nipissing pass east of North Bay had been opened and a second low water stage had occurred. The data thus far collected seem to admit a possibility that this was a stage of temporary marine submergence; but further careful studies and more accurate measurements in that most critical field will be needed before the truth is known. With repeated uplifts, the waters of the Huron and Michigan basins rose from this low level, the "low water" beaches were drowned (except north of the Nipissing pass), and the Port Huron outlet was re-established. Since then the Nipissing plane has been raised far out of water. The Algoma beach (*i*) seems to mark the most important pause in this period of comparatively recent uplift.